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# Assessment of the geometrical characteristics of hazelnut intensive orchard by an Unmanned Aerial Vehicle (UAV)

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***Abstract*—Assessing the canopy characteristics of the trees is essential for optimizing agronomic management. In fact, it has been shown that there is a strong relationship between the geometric characteristics (i.e. size and volume) of the tree and quantity of water and fertilizer used for crop management. Normally, tree measurements are carried out using manual method, that is time consuming so seems to be more feasible on few trees. For the first time, this study tested the UAV technology on intensive and high-density hazelnut orchards. The aim was to propose a new automated method for the hazelnut canopy characterization, using a DJI Phantom 4 Multispectral UAV. The results showed a good performance of the method proposed for evaluating the width and the actual volume of the canopy. A criticism was revealed for the height of the canopy probably due to the UAV survey. Anyway, the measurements conducted on the point cloud resulted less time-consuming per each tree and more punctual than manual ones, so less exposed to errors.**

**Keywords—** ***canopy volume, canopy width, canopy height, Tonda Francescana® cultivar***

## I. INTRODUCTION

The use of vehicle without pilot (UAV), for optimal surveying of the plantation from 3D point cloud maps and digital surface models (DSM), had accelerated the extrapolation of precious information for optimal agriculture management. [1]

A quick but accurate estimation of the canopy crop characteristics, as height and volume, is a critical point of the agronomic management of an orchard. In fact, this information could be used both for the management of the canopy and the yield, and for the management of the input of the cultivation process (as water and fertilizer) for a sustainable agriculture. So, the knowledge of the actual volume of the canopy could be used to optimize cultural practices [2]. Recently, the assessment of the tree canopy characteristics using high-resolution UAV imagery was tested in different orchards, as olive [3], peach [4], almond [5], apple [6] and cherry [7], with promising results.

Hazelnut trees have some specific characteristics, such as large leaves and dense foliage. To the best of our knowledge, the canopy for hazelnut monitoring by UAV has not been explored yet. The primary aim of this research was to assess the UAV photogrammetry for a hazelnut orchard. The specific objectives of the study were to 1) test the technology on intensive, high-density and super high-density hazelnut orchards and 2) propose a new method for the punctual and complete characterization of the hazelnut canopy volume. For the analysis, also a campaign of manual measurements was conducted.

## II. MATERIALS AND METHODS

### A. Study site description and tree sampling

The experiment was conducted, during the growing season of 2021, in the experimental orchard of the Department of Agricultural, Food, and Environmental Sciences of the University of Perugia, located in the Umbria region in Central Italy (42°58′22.82″N, 12°24′13.02″E) on 4 ½ -years-old hazelnut orchard, with three tree densities: 625 plants $ha^{-1}$, spaced 4 m between rows and 4 m on the row, that is the control treatment, being the density used by farmers in the new intensive orchards; 1250 plants $ha^{-1}$, spaced 4 m x 2 m and 2500 plants $ha^{-1}$, spaced 4 m x 1 m (Fig.1). All plants, grafted on no – suckering rootstock, were trained as single trunks with four branches each. The measurements were made on plants trained with three different plantation distances, from 4 meters to 1 m on the row, to assess the applicability of UAV technology even with very close plants. The plants are distributed on 6 rows, with the three densities of plantation in each row, composed by variety of hazelnut Tonda di Giffoni, in the first three rows, and by with Tonda Francescana® in the next three rows. In this preliminary research, the plants studied belonged only to the hazelnut cultivar Tonda Francescana®. The manual measurements have been carried out on 9 trees, three per rows and per tree density (Fig.1). This seemingly limited number is due to the laboriousness of the manual measurements related to the test as well as the need to develop the most appropriate methodology for using the UAV in the hazelnut orchard.

### B. Manual Measurements

The manual measurement of crop parameters, such as plant height and canopy volume, was carried out by using a meter. Specifically, through these instruments the height of the plant and the height of the trunk has been measured by a trained operator standing in front of the plant, collecting a single measurement per parameter. The height of the canopy was



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calculated as difference between the height of the plant and the height of the trunk. Other characteristics, such us width and thickness of the canopy, were measured as the distance between the sides; specifically, the distance between the north and south sides of the canopy represents its width, and that between the west and east sides of the canopy its thickness. Since manual measurement of tree size parameters consisted of only one measure per parameter, it was estimated by the operator an average value per each one. The width and thickness of the canopy were used to calculate the radius of the canopy area, assimilated to a regular circle. Later, together with the height of the canopy, they were used to calculate the volume of the canopy, which has been assimilated to a cylinder according to [8].

### C. Data acquisition UAV images

During the 2021 growing season, the images of hazelnut trees were collected six times from May to November, but, according to the paper's aim, only the data collected in July, August and September 2021 were considered. The acquisition was made using a DJI Phantom 4 Multispectral UAV [9]. The UAV flight was done in a flight-based automated manner, designed and executed by the App DJI GSPro installed on the Apple iPad. The flight plan had the following parameters: designed as a polygon grid, with flight altitude at 10m, side overlap at 75% and forward overlap at 75%, velocity al 1.5-2 m/s and the capture mode "Hover &Capture at Point". The ground resolution (GSD – Ground Sample Distance) was set 0.5 cm/pix.

The images captured from the UAV are georeferenced, but in order to improve the geolocation accuracy, the georeferencing of the point cloud was done using ground control points (GCPs) distributed in the survey area. The coordinates of the GCPs were measured using the Network Real Time Kinematic (NRTK) Positioning, so the position of the receiver points GNSS is obtained in real time with centimeter precision. The relative and absolute orientation of the frames was performed by aerial triangulation with a bundle adjustment algorithm. The tie points of the frames were automatically identified using an image-matching algorithm. The GCPs, whose coordinates were known from the GNSS survey, were manually identified on the frames and collimated one by one [10].

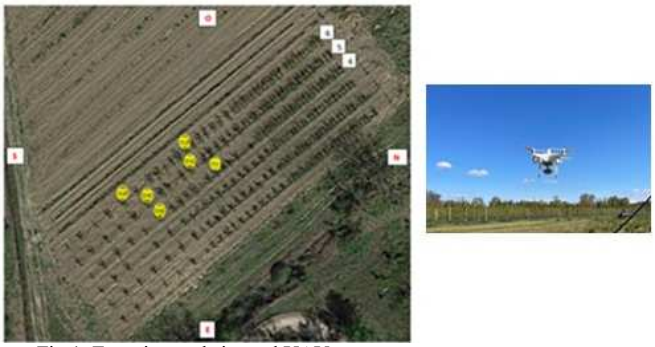

Fig.1. Experimental site and UAV survey

### D. Point cloud reconstruction

Standard RGB images were acquired with a regular grid pattern, frontal overlap of 75%, The red-green-blu (RGB) images collected by the UAV were used to generate a 3D point cloud using the Agisoft Metashape software [11] by the Structure From Motion algorithm. The detailed procedure is described in [12]. In the left of the Fig. 2 the 3D point cloud obtained for the survey of 12th July 2021. The GCPs were used for orienting the images during the optimization and for georeferencing the photogrammetric model and point cloud in the global datum WGS 84. The errors obtained for the markers used as checkpoints and as control points resulted lower than 0.02 m (Total Error Control Points: 0.0173 m; Check Points: 0.0193 m).

### E. Characterization of hazelnut trees

From the 3D point cloud, the open source Cloud Compare software was used. In particular, the command "segment" was used to cut out the single canopy of each tree. Then, a model of the surface was created in GRID format, using the command "Convert Cloud 2D raster". Finally, the GRID model was imported in QGis (Fig.3a).

The file raster in GIS ambient was elaborated to obtain the radius and the height of the canopy; in particular:

- The radius was calculated as the mean of the width of the canopy evaluated on eight different directions with an inclination of 22°30' (Fig. 3b);
- The height of the canopy was obtained from the difference between the maximum and the minimum elevation of the file raster (Fig. 3c).

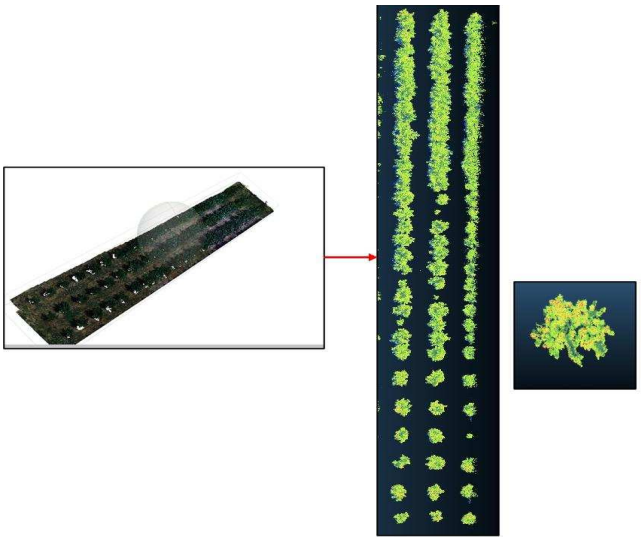

Fig.2 From the left, the 3D point cloud, the model of the hazelnut trees on Cloud Compare software and a single canopy tree

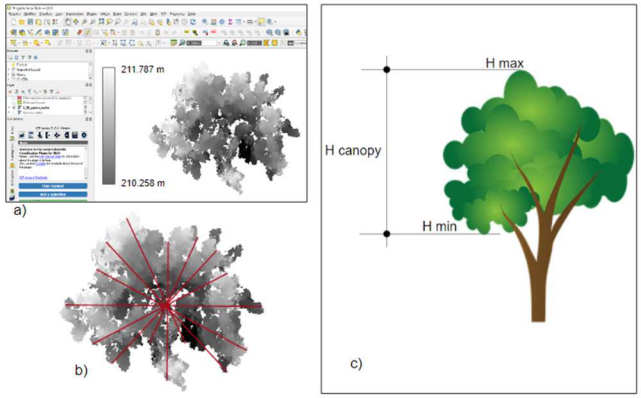


Fig.3.Determination of the radius (a,b) and the height (H) of the canopy (c)



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### F. Determination of the canopy volume and area

The canopy volume for each chosen tree was evaluated in two different ways (Fig.4):

Method 1 (later called traditional): the canopy was assimilated to a cylinder having as its base a circumference of radius equal to the average radius of the canopy and as height the difference between the maximum average dimension of the canopy and the trunk height.
Method 2: the volume has been evaluated considering the shape of the canopy obtained from the 3D point cloud. From the raster file of the canopy, the volume was obtained in GIS environment by evaluating the volume between the DSM and a horizontal plane passing through the lowest point of the same.

The parameters determined were canopy heights, canopy radius and canopy volume (Table 1).

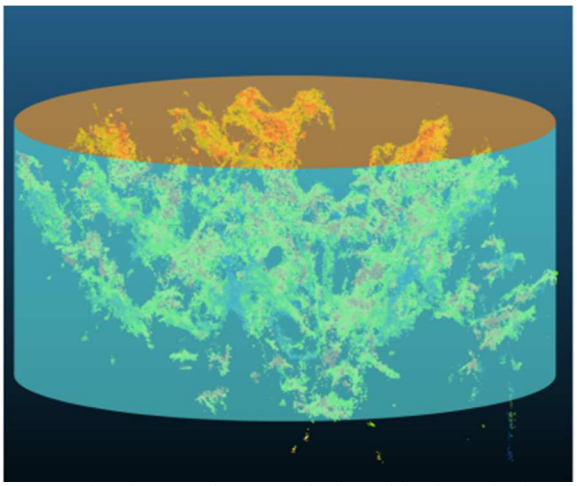

Fig.4. Comparison between the two methods used for the evaluations of the canopy volume

## III. Results and Discussion

For the super-intensive density (2500 tree $ha^{-1}$) hazelnut orchard, the method proposed resulted not suitable for the recognition of the canopy of the single tree, since they were too close. In fact, during the growing season the proximity of the trees create a superimposition of the canopies. This situation did not allow defining neither the shape nor the border of the hazelnut tree by UVA; therefore, this part of the orchard has been discarded in the analysis.

### A. Evaluation of the tree characteristics

The measures relating to the width of the canopy, assimilated to a circumference, resulted to be very similar with manual and UAV survey for plants trained with a density of 1250 tree/ha, showing respectively a radius of 88.66 cm (standard deviation of 7.08 cm) and 88.88 cm (standard deviation of 32.09 cm) (Table 1).
In plants trained with 625 tree/ha the average radius of the canopy was 89.31 cm (standard deviation of 9.50 cm) with manual measurement and 98.51 cm (standard deviation of 32.09 cm) from the UAV (Table 1). This difference could be due to the more expanded, and therefore wider, posture of the canopy of the plants with greater distance between them. This determines, in the manual measure, in which the average and not maximum width of the canopy is measured, a slight underestimation. Overall, the canopy radius has a relatively low total Root-Mean-Square Deviation (RMSD) value of 20.913, indicating a good match between the two methods of survey.
It is important to point out that the canopy size parameters measured manually represent the mean value of the canopy, derived from a single one measure per each size parameter. On the contrary, the size parameters obtained from UAV survey were calculated as the mean of a set of exact measures of all the canopy. So with manual measurement, you get an average value directly while with UAV survey this is calculated as an average of more measurements. The measurement of the size of hazel plants by UAV, requiring further processing, is more laborious, but more "punctual" than manual one.

The height of the canopy was lower with the method 2, with a greater drop in plants with a lower planting density, from 1.7 m (standard deviation of 0.084 m) to 1.4 m (standard deviation of 0.01m) versus 1.71 m (standard deviation of 0.13 m) and 1.51 m (standard deviation of 0.23m) measured in plants with higher density (Table 1). These initial results indicate that, in the hazelnut, the survey of the canopy height, measured with digital photogrammetry from UAV, could require a change in the survey because the calculated values have high ranges of variation and very different from those obtained with manual measurement of plants, not in agreement to those obtained in other fruit species [13-14].

TABLE 1: Tree characteristics with manual and UAV survey

| **DENSITY OF PLANTATION (N. TREE $HA^{-1}$)** | Tree characteristics with manual and UAV survey | | | |
|---|---|---|---|---|
| | ***Radius (cm) manual survey*** | ***Radius (cm) UAV survey*** | ***Tree Height (m) method 1*** | ***Tree Height (m) method 2*** |
| 625 | 89.31 | 98.51 | 1.70 | 1.40 |
| 1250 | 88.66 | 88.88 | 1.71 | 1.51 |
| STAND. DEV. (625) | 9.495 | 8.422 | 0.084 | 0.097 |
| STAND. DEV. (1250) | 7.082 | 32.09 | 0.13212 | 0.22713 |
| RMSD TOTAL | 20.91 | | | |
| RMSD (625) | 12.06 | | | |
| RMSD (1250) | 27.01 | | | |



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*B. Evaluation of the canopy volume*

In table 2 were reported the canopy volume values obtained from the two methods described above during the season. Each tree was identified by a code X_YY where X is the row and YY is the plant number. For the survey of August there was a bug in the 3D point cloud model, so the 6th row can't be included in the present analysis. As shown in table 2, the values obtained using method 2 resulted very different from those obtained from method 1. As expected, the canopy volume estimated with the method 1 seems to overestimate the actual value. The greater difference was obtained in August for the tree 4_31 (75%) and in September for the tree 6_32 (75.6%). The mean of the differences is 53%.

TABLE 2. CANOPY VOLUME EVALUATION

| **PERIOD** | ***TREE*** (row number and tree position per row) | CANOPY VOLUME ($m^3$) | |
|---|---|---|---|
| | | ***METHOD 1)*** | ***METHOD 2)*** |
| JULY | 4_31 | 5.53 | 2.216 |
| | 4_38 | 3.85 | 2.203 |
| | 5_33 | 5.16 | 2.968 |
| | 5_38 | 3.87 | 2.266 |
| | 6_32 | 4.34 | 1.799 |
| | 6_39 | 5.79 | 2.820 |
| AUGUST | 4_31 | 5.64 | 1.400 |
| | 4_38 | 4.04 | 2.084 |
| | 5_33 | 4.81 | 2.412 |
| | 5_38 | 3.70 | 2.183 |
| SEPTEMBER | 4_31 | 4.01 | 2.113 |
| | 4_38 | 3.44 | 2.028 |
| | 5_33J | 4.04 | 2.125 |
| | 5_38 | 3.84 | 1.428 |
| | 6_32 | 4.94 | 1.206 |
| | 6_39 | 5.89 | 1.780 |

In Table 3 were reported the canopy volume obtained from the manual measurement and from the UAV applying the method 1. As assessed above the method 1 seems to overestimate the actual volume, but the calculation procedure is similar to the manual one, so the comparison seems to be more reasonable between these two results (from manual survey and from UAV survey-method 1). Considering all the data, the canopy volume of the plants with density of 625 tree/ha is very similar, respectively 4.27 $m^3$ (standard deviation of 0.786) and 4.30 $m^3$ (standard deviation of 0.965); on the contrary, the canopy volume of plants with high planting density was slightly different, with a value of 4.23 $m^3$ (standard deviation of 0.777) for manual measurements and 4.81 $m^3$ for UAV measurements-method 1 (standard deviation of 0.633) (Table 3). The total Root Mean Square Deviation (RMSD) value was 1.069, indicating a good match between the two methodologies.

These results in accordance to those observed in peach and blueberry, where the authors [4-14] obtained a good accuracy of cloud measurements compared to manual ones. This result is due to the fact that the measure from UAV allows to delineate the tree canopy in the single detail of shape, and not as in the manual measures assimilating it to a simple cylinder, even though the canopy of the hazelnut tree, and tree in general, is not a regular figure but distributed on 3 or 4 main branches. According to [2], overall results indicate that the flight altitude and resulting spatial resolution strongly govern the correlation with the ground measurements. In this preliminary study, due to the limited number of trees measured manually, it is impossible to divide it into a validation set. Therefore, manual measurements are subject to a high variability linked to the subjectivity of the operator performing a single average measurement, in addition to the temporal burden.

TABLE 3 – CANOPY VOLUME WITH MANUAL AND UAV SURVEY

| **DENSITY OF PLANTATION (TREE $HA^{-1}$)** | CANOPY VOLUME WITH MANUAL AND UAV SURVEY | |
|---|---|---|
| | ***Canopy Volume ($m^3$) – Manual measurements*** | ***Canopy Volume ($m^3$) - UAV measurement (method 1)*** |
| 625 | 4.27 | 4.30 |
| 1250 | 4.23 | 4.81 |
| STAND. DEV. (625) | 0.786 | 0.965 |
| STAND. DEV. (1250) | 0.777 | 0.633 |
| Root-mean-square deviation RMSD (TOTAL) | 1.069 | |
| RMSD (625) | 0.959 | |
| RMSD (1250) | 1.169 | |



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## IV. Conclusion

This study tested, for the first time, the UAV technology on different density of a hazelnut orchards. In this paper the first year of experimentation were presented. The survey allowed to adopt a new method for the punctual and efficient characterization of the hazelnut canopy volume as well as for the definition of the canopy width, being able to measure the canopy in its precise conformation, while manually it is similar to a simple cylinder. On the other hand, the results showed a critical point on methodology of surveying from a multispectral UAV. In fact, the multispectral UAV allows an acquisition from above the canopy and it has shown some limits linked to the correct measurement of the height of the canopy. The lower part of the canopy could be hindered by the its own shape and it seems to condition the visibility of the lower sections, limiting the precise measurement. On the other hand, the measurements conducted on the point cloud resulted less time-consuming and more punctual compared to the manual ones, so more precise. The research will continue with the validation of the proposed methodology on a greater number of plants.

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